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# DESCRIPTION
AND
# USE
OF A
# THERMOMETER
FOR MEASURING
## THE HIGHER DEGREES OF HEAT,
FROM A RED HEAT
UP TO THE STRONGEST THAT VESSELS MADE
OF CLAY CAN SUPPORT.

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By JOSIAH WEDGWOOD, F.R.S. & A.S.
AND POTTER TO HER MAJESTY.

Extracted from a Paper communicated by him to the ROYAL
SOCIETY May 9th, 1782, and publiſhed in Vol. LXXII.
OF THE
PHILOSOPHICAL TRANSACTIONS.

LONDON:
PRINTED BY JOSEPH COOPER.
M.DCC.LXXXIV.

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# DESCRIPTION, &c.

A MEASURE for the higher degrees of heat, ſuch as the common Thermometers afford for the lower ones, has ever been a deſideratum, both to the philoſopher and the practical artiſt. Moſt of thoſe productions of art, which owe their exiſtence to the action of fire, have their beauty and value eſſentially influenced by minute deficiencies or exceſſes of heat; and the artiſt is frequently precluded from availing himſelf of the advantages which might reſult even from his own experiments, where the heat has paſſed under his own eye, by not being able to aſcertain the degree of ſuch heat; much more ſo from thoſe of others, who have no means of communicating to *him* even the imperfect ideas which they have *themſelves* of the heat made uſe of in their operations. The common diſtinctions of *red*, *bright red*, and *white* heat are, as will appear hereafter, totally inadequate to the purpoſe; they are by far too indeterminate, and of too great latitude; the brightneſs or luminouſneſs of fire increaſing, with its force, through numerous gradations, which can neither be expreſſed in words nor diſcriminated by the eye.

The force of fire, in its higher as well as lower ſtages, can no otherwiſe be juſtly aſcertained, than by its effects upon ſome known body; ſuch as the *expanſion* of mercury or ſpirit of wine, by which the heat is meaſured, in common thermometers, as far as thoſe volatile fluids can bear. The thermometer here offered to the public depends upon another effect of fire, oppoſite in kind, but equally conſtant, uniform, and meaſurable; a *diminution* which it produces in the bulk of earths and ſtones of the argillaceous order.

This diminution begins to take place in a low red heat; and proceeds regularly, as the heat increaſes, till the clay becomes vitrified, and conſequently to the utmoſt degree that furnaces or veſſels made of this material can ſupport. Some good clays, of the moſt unvitreſcible kind, I have found to diminiſh, in the ſtrongeſt of my own fires, conſiderably more than one-fourth part in every dimenſion.

The *contraction*, then, of this ſpecies of matter affords as true a meaſure for theſe high degrees of heat, as the *expanſion* of mercury or ſpirit does for the low ones; and with this advantage, that whereas *expanſion* ceaſes with the heat which produced it, thoſe thermometers, when grown cold, retaining no traces of the heat they had paſſed through; the *contracting* on which this thermometer depends, is a permanent effect, the maſs when grown cold being found diminiſhed in bulk, proportionably to the heat it had undergone; ſo that the degree of heat, in any particular operation, is here not determined by a ſingle tranſient obſervation made in the fire itſelf, but its meaſure is preſerved, and may be examined at any future time.

This thermometer is ſimple, eaſy to be underſtood, and as eaſily made uſe of. It conſiſts of two parts only; viz. little ſquare pieces of clay, called *thermometer-pieces*, and a *gage* to meaſure their contraction.

The gage, as originally deſcribed in the Tranſactions, conſiſted of two flat braſs rulers, twenty-four inches long, with the ſides exactly ſtreight, divided into inches and tenths, or 240 equal parts; fixed flat upon a braſs plate, half an inch aſunder at one end, and three tenths of an inch at the other; ſo as to include between them a long converging canal, at the wider end of which one of the pieces of clay, half an inch broad, would juſt enter to 0, or the commencement of the diviſions.

Let us ſuppoſe this piece to be diminiſhed in the fire two fifths of its bulk, that is, reduced in its breadth from five tenths of an inch to three tenths; being now applied in the canal, and gently puſhed or ſlid along, it would paſs on to the narrow end, or the 240th diviſion: if diminiſhed only half ſo much, it would go no farther than the middle, or the 120th diviſion; and at any other degree of contraction, if the piece be paſſed along till it reſts againſt the converging ſides, the diviſion at which it ſtops will be the meaſure of its contraction, and conſequently of the degree of heat it has undergone. Thus if one of the pieces be put into a crucible along with ſome copper, and taken out as ſoon as the copper melts, it will now ſlide freely to 27 of the gage: tried in the ſame manner along with gold, it will diminiſh a little more, and go to 32: whilſt a piece which has been expoſed to the heat neceſſary for bringing caſt iron into fuſion, is found ſo far diminiſhed as to paſs to 130. We therefore ſay that copper melts at the 27th, gold at the 32d, and caſt iron at the 130th degree of this thermometer. Theſe pieces may therefore be conſidered as the mercury, and the converging ſides of the gage as the containing tube and ſcale, of the common thermometer.

As a gage of the above ſize might be inconvenient, I have now reduced it to one fourth of the length, by dividing it into two parts, placed ſide by ſide, and making the degrees half-tenths of an inch inſtead of tenths; the widths at the two extreme ends being the ſame as in the other. Nor does this alteration in the ſcale make any difference in meaſuring the degrees of heat; for both ſcales divide the two-tenths of an inch into the ſame number of equal parts, viz. 240.

All the little maſſes or thermometer-pieces are made of the ſame clay, which has been thoroughly mixed together, and paſſed ſucceſſively through finer and finer ſieves, the laſt of which is a ſilk lawn, the interſtices of whoſe threads are leſs than the 150,000th part of a ſquare inch.

The pieces are all formed by *one and the ſame* mode of operation, which ſome late experiments have ſhewn to be neceſſary in order to avoid errors, as mentioned hereafter. The method is, by preſſing the ſoft clay through apertures in the bottom of a cylindrical iron veſſel, by which it is formed into long rods, and theſe are afterwards cut into pieces of proper lengths. Theſe pieces, when perfectly dry, are adjuſted, one by one, ſo as to paſs, breadthwiſe, to 0 of the gage ; a work of no ſmall delicacy, as the adjuſtment ought to be exact, at leaſt to the 120th part of the tenth of an inch, which correſponds to one degree of the ſcale. If, from inadvertence in the operator, any piece enters a degree or two farther, that degree is marked upon the bottom of the piece, and is always to be deducted in meaſuring heat by it.

The pieces, thus fitted to 0 of the gage, are baked in an oven with a red heat, in order to give them ſome firmneſs or hardneſs, that they may bear package and carriage, and to prepare them for being put afterwards immediately into any fire without danger of their burſting. The heat made uſe of in this operation is generally about ſix degrees, that is, the pieces are diminiſhed by it ſo as to paſs to 6 of the gage, ſometimes a little more, and ſometimes leſs. Theſe circumſtances are immaterial with reſpect to their future uſe for meaſuring any degree of heat *above* that which they have thus undergone; for pieces that have ſuffered any inferior heat anſwer equally for meaſuring any higher ones, as thoſe which have never been expoſed to fire at all.

For meaſuring degrees of heat *lower* than theſe pieces have paſſed through in the baking, the operator is furniſhed with ſome unburnt ones, with which he muſt take the neceſſary precautions to prevent their burſting, from too ſudden heat, upon firſt expoſure to the fire. In this caſe, he may ſometimes meet with a phenomenon little expected, an *enlargement* of the bulk; for all the pieces ſwell a little on the approach of redneſs, but reſume their former bulk by the time they are *red-hot throughout*; and it is from *that point* that the thermometric diminution commences.

As this thermometer, like all others, can expreſs only the heat felt by itſelf, the operator muſt be careful to expoſe the pieces to an equal action of the fire with the body whoſe heat he wants to meaſure by them. In kilns, ovens, reverberatories, under a muffle, and wherever the heat is pretty ſteady and uniform, the means of doing this are too obvious to need being mentioned; but for experiments in a naked fire, where the heat is neceſſarily more fluctuating, and different in different parts of the fuel, ſome precautions will be neceſſary.

The thermometer-piece may, generally, be put into the crucible along with the ſubject matter of the operation, as with all metals, powders, &c. Where the matter is of ſuch a kind as to vitrify and ſtick to it, the piece may be defended by previouſly putting it into a caſe made of crucible clay. The ſmallneſs of the pieces will admit of this being done without inconvenience, at leaſt in any but the very ſmalleſt crucibles; and for theſe, the caſe may be put in cloſe to the crucible, ſo as to form as it were an addition to its bulk on the outſide. But if we were to judge of the heat of *large* crucibles from a thermometer-piece thus placed on the outſide, we ſhould be deceived, as the piece in its little caſe will receive the heat ſooner than the matter in the larger veſſel; whereas in *ſmall* ones, the caſe and crucible being nearly of the ſame dimenſions, there is little danger of error from this cauſe.

Theſe thermometer-pieces poſſeſs ſome ſingular properties, which we could not have expected to find united in any ſubſtance whatever, and which peculiarly fit them for the purpoſes they are here applied to.

1. When baked by only moderate fire, though they are, like other clays, of a porous texture, and imbibe water; yet, even when ſaturated with the water, their bulk continues exactly the ſame as in a dry ſtate.

2. By ſtrong fire, they are changed to a porcelain or ſemivitreous texture; nevertheleſs, their contraction, upon farther augmentations of the heat, proceeds regularly as before, up to the higheſt degree of fire I have been able to produce.

3. They bear ſudden changes of ſtrong heat and cold; may be dropt at once into intenſe fire, and, when they have received its heat, may be plunged as ſuddenly into cold water, without the leaſt injury.

4. Even when ſaturated with water in their porous ſtate, if they have been burnt to any degree beyond the ſtate of crude clay, they may be thrown immediately into a white heat, without burſting or receiving any injury.

5. Sudden cooling, which alters both the bulk and texture of moſt bodies, does not ſeem at all to affect theſe, at leaſt not in any quality ſubſervient to thermometric purpoſes.

The uſe and accuracy of this thermometer for meaſuring, *after an operation*, the degree of heat which the matter has undergone, will, from what has been ſaid, be apparent. The foregoing properties afford means of meaſuring it alſo, eaſily and expeditiouſly, *during the operation*, ſo that we may know when the heat has riſen to any degree previouſly determined upon. The thermometer-piece may be taken out of the fire in any period of the proceſs, and plunged immediately into cold water, ſo as to be fit for meaſuring by the gage in a few ſeconds of time. At the ſame inſtant another piece may be introduced into the place of the former, to be taken out and meaſured in its turn, and thus alternately till the deſired degree of heat is obtained; or, it may be adviſeable, on ſome occaſions, as the cold piece will be two or three minutes in receiving the full heat, to have two or more pieces, according to convenience, put in together at firſt, which may be taken out in ſucceſſion, in order to examine the heat at ſhorter intervals. It will be unneceſſary to ſay any thing farther upon precautions or procedures, which the very idea of a *thermometer* muſt ſuggeſt, and in which it is not apprehended that any difficulty can occur, which every operator will not readily find means to obviate.

The number and extent of the degrees, in this as in other thermometers, are unavoidably arbitrary. Thoſe I have fixed upon appear ſufficiently commodious, and the method of diviſion is ſuch, as to ſecure the eſſential point, the perfect correſpondence of all the thermometers with one another, the ſame degrees denoting, in all of them, preciſely the ſame heats.

But although it is very neceſſary that *ſtandard* thermometers, or thoſe for *general* uſe, ſhould thus ſpeak one univerſal language, yet any experimenter or manufacturer, who wiſhes only to regulate the heats employed in his own operations, may have a thermometer of this kind prepared, at leſs expence, for his own particular uſe, whoſe language he may ſoon be able to underſtand as a directory to himſelf, though he cannot interpret it to another, or at leaſt not without an actual compariſon by experiment.

But the moſt important advantage, which may be derived from partial thermometers is, that any period or interval of heat, wanted to be meaſured in particular arts or manufactures,

factures, may be ſubdivided to any degree of minuteneſs, and any part, or the whole length of the ſcale, be appropriated to that interval only. Thus, for burning-in enamel colours, where the greateſt heat does not exceed ſeven degrees, a gage may be ſo adjuſted, by making the ſides leſs converging, that theſe ſeven degrees ſhall occupy any extent on the ſcale. In like manner a gage may be made for potters or porcelain-manufacturers, glaſs-makers, founders in any of the metals, for different kinds of experimental enquiries, &c. to meaſure, upon an enlarged ſcale, any of their particular periods of heat, of greater or leſs extent; ſo that the ſtandard thermometer may be conſidered as a general map of a kingdom, and theſe partial ones as minute ſurveys of particular diſtricts drawn to a larger ſcale.

To give ſome idea of the language of this thermometer, and aſcertain ſome fixt points for the compariſon of its degrees, the following obſervations are ſelected from a great number of others, which I have given an account of in the volume of the Philoſophical Tranſactions referred to at the beginning of this paper. Mr. Alchorne, aſſay-maſter at the Tower, was ſo obliging as to make the experiments with me there, upon the pure metals, for determining the melting heats of copper, ſilver and gold.

Some farther experiments, which I have but juſt finiſhed, and communicated to the Royal Society, enable me now to aſcertain the value of theſe degrees in a more ſatisfactory manner, and to expreſs them in a language which long uſe has rendered familiar to us; I mean, to connect this thermometer with Fahrenheit's, and to annex a column, ſhewing the diviſions of his ſcale that correſpond to the reſpective degrees of mine.

| | | Wedg. | Fahr. |
|---|---|---|---|
| Red heat, fully viſible in day light | | 0 | 1077 |
| The heat by which my enamel colours are burnt in | | 6 | 1857 |
| Braſs melts | | 21 | 3807 |
| Swediſh copper melts | | 27 | 4587 |
| Fine ſilver melts | | 28 | 4717 |
| Fine gold melts | | 32 | 5237 |
| Welding heat of iron | Leaſt | 90 | 12777 |
| | Greateſt | 95 | 13427 |
| Greateſt heat we could produce in a common ſmith's forge | | 125 | 17327 |
| Caſt iron melts | | 130 | 17977 |
| Greateſt heat I have produced in an air furnace eight inches ſquare | | 160 | 21877 |

Thus we find, that though the heat in which copper melts is called a *white heat*, it is only 27 degrees of this thermometer: the welding heat of iron, or 90 degrees, is likewiſe a *white heat*; even 130, at which caſt iron comes into fuſion, is no more than a *white heat*; and ſo on to 160 and upwards is all a *white heat* ſtill; including, in the whole, an extent of above 16000 of Fahrenheit's degrees. This ſhews abundantly how vague ſuch a denomination muſt be, and how inadequate to the purpoſe of giving us any clear ideas of what we have been accuſtomed to conſider as *one* of the *three* diviſions of heat in ignited bodies.

It may be proper to take notice alſo of the *extent* of the province of this thermometer, comparatively with that of mercurial ones, and with ſome other intervals of the lower ſtages of heat with which we are better acquainted. The extent meaſurable by this thermometer, reckoning only up to its 160th degree, the higheſt I have produced in a common air furnace about eight inches ſquare, is 19 times as great as from freezing water to full ignition;—34 times as great as from the freezing point of mercury to its boiling point, which makes the utmoſt limits of mercurial thermometers;—109 times as great as from freezing water to boiling water; —and more than 300 times as great as from freezing water to the vital heat.

In the volume of the Tranſactions above mentioned, I have given an account of the heats of the copper and iron foundaries, determined by paſſing the thermometer-pieces, in their caſes, through the furnaces, along with the metals, and of the heats uſed in the making of glaſs, and for burning the different kinds of earthen ware, by firing the pieces along with the glaſs or ware, in the reſpective furnaces or kilns. But this thermometer affords means of doing much more, and of going farther in theſe meaſures than I could at firſt even have expected: it will enable us to aſcertain the heats by which ſome of the porcelains, and any of the earthen wares, of diſtant nations and different ages, have been fired. For it appears, 1. That theſe bodies, in virtue of the argillaceous earth which makes an eſſential part of their compoſition, are capable of having *their bulk diminiſhed by fire.*

*fire.* 2. That the diminution which they muſt neceſſarily have received in the firſt baking is not alterable by repaſſing them through the *ſame degrees of heat which they had undergone before*; but, 3. That as ſoon as the heat begins to *exceed thoſe limits*, a farther diminution begins to take place. If therefore a fragment of the given ware be firſt meaſured in the gage, and afterwards expoſed along with a thermometer-piece to a gradual fire, examining the fragment every now and then till it is found juſt beginning to diminiſh, we may be ſure of having given it the full degree of heat which it had been baked with at firſt, and what that degree is will be ſeen by meaſuring the thermometer-piece.

By means of this thermometer, ſome intereſting properties of natural bodies may likewiſe be diſcovered or more accurately aſcertained, and perhaps the genus of doubtful bodies determined. Jaſper, for inſtance, is found to diminiſh in the fire, as the clays and ſoap-rocks do; granite, on the contrary, has its bulk enlarged by fire; whilſt flint and quartzoſe ſtones are neither enlarged nor diminiſhed. Theſe experiments were made in fires between ſeventy and eighty degrees of this thermometer. A ſufficient number of facts like theſe, compared with each other, and with the properties of ſuch natural or artificial bodies as we wiſh to find out the compoſition of, may lead to various diſcoveries, of which I have already had ſome promiſing appearances.

By repeating and accompanying with theſe thermometer-pieces any experiments hitherto made, as thoſe of Mr. Pott and Mr. Achard, to which no degree of heat could be affixed at the time of making them, they may now have their reſpective heats aſcertained, and thereby be rendered much more intelligible and uſeful, to the reader, the experimenter, and the working artiſt.

Many other applications and uſes of a meaſure for theſe higher degrees of heat will, doubtleſs, occur. I ſhall mention only one, that of determining the comparative ſtrengths of different ſpecies of coals or other fuel. If equal quantities of each be burnt ſeparately, in the ſame furnace, with the ſame draught of air, and all other circumſtances, as nearly alike as poſſible, a thermometer-piece in its caſe being placed each time in the middle of the fire; it is plain, that as the pieces expreſs always the heats which they have felt, they will be juſt *criteria* of the intenſities of the reſpective fires, and conſequently of the comparative ſtrengths of the fuels.

I flatter myſelf that a field is thus opened for a new kind of thermometrical enquiries, and that we ſhall obtain clearer ideas of the differences of the degrees of ſtrong fire, and their correſponding effects upon natural and artificial bodies; thoſe degrees being now rendered accurately meaſurable, and comparable not only with each other, but likewiſe with the lower ones, which are the province of the common thermometer.

⁂ AS the public are in full poſſeſſion of this diſcovery, I ſhould gladly be excuſed from the attention and trouble of ſupplying the thermometers for ſale, which will interfere very much with my fixed engagements, and at a time of life, too, when additional cares of this kind might well be diſpenſed with. But I find myſelf called upon, from abroad as well as by my friends at home, to furniſh thermometers complete and fit for immediate uſe; which requeſt I am the more inclined to comply with, for a time at leaſt, from my own fears, that in other hands, all my labour may be rendered ineffectual; and that the thermometer itſelf may be brought into diſcredit before its general utility is eſtabliſhed, as well by inaccuracies in the execution ſcarcely avoidable at firſt; as, by the want of thoſe inſtruments and machines with which I have been obliged to ſupply myſelf for theſe purpoſes. For the formation and adjuſtment of the pieces require thoſe peculiar niceties and precautions in the manual operations, which theory will not ſuggeſt, and which practice in the working of clay can alone teach; the uniformity of their diminutions by fire being influenced very conſiderably by minute and ſeemingly inſignificant circumſtances, which a tedious courſe of very perplexing experiments has been neceſſary for aſcertaining, and of which, as ſoon as the whole of thoſe experiments is completed, I propoſe to give ſome farther account.

For the ſame reaſons, I have thought it neceſſary to have the partial thermometers alſo made under my own inſpection, and for this purpoſe have prepared a ſufficient quantity of clay for making many hundred thouſands of the pieces; for in theſe, as well as in the general or ſtandard ones, it is eſſential that all the pieces be alike, or diminiſh equally in equal fires.

THE END.

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# POSTSCRIPT.

In conſequence of the experiments alluded to in the laſt page, I now form the thermometer pieces of an argillaceous compoſition,* which poſſeſſes ſome advantages over the former clay, and which differs from it particularly in reſpect to two of the properties above ſtated; *viz.* ſuffering no *enlargement of bulk* (ſee page 9, 10) in the baking prior to the commencement of the thermometric diminution; nor receiving, in any degree of heat, the leaſt appearance of a *porcelain texture* (p. 12) but continuing in a bibulous ſtate after paſſing through the ſtrongeſt fires I can excite.

The pieces are all dried by the heat of boiling water, and adjuſted in the gage *immediately*, as they are ſubject, in their unbaked ſtate, to imbibe moiſture again from the air, and to have their bulk thereby ſenſibly

*V. Phil. Tranſ. vol. LXXVI, p. 390

bly enlarged; a circumſtance of no conſequence *after* they have been adjuſted.

In *adjuſting* the pieces, (p. 8) it has been found beſt that the ſmooth and cloſe ſurfaces, which they receive in their formation while ſoft, be preſerved entire and unhurt; and therefore, inſtead of paring, or rubbing down, thoſe which may be a little too large, I now mark on the hindmoſt end, (which has its angular edge beviled off) the number of degrees they go ſhort of 0; ſo that, in all experiments with pieces that have any number upon them, if the number is on the *hindmoſt end*, it muſt be *added to*, and if on the *foremoſt end*, *ſubtracted from*, the degree which the piece goes to after the experiment.

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